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RESEARCH MEMORANDUM

EXPERIMENTAL INVESTIGATION OF EFFECT OF HIGH-ASPECT-RATIO ROTOR BLADES ON PERFORMANCE OF CONSERVATIVELY DESIGNED TURBINE

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CLASSIFICATION CHANGED

To UNCLASSIFIED

By authority of Naca Res. abs. Effective +RN-113 Date 3-14-57
NB 4-3-57

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
May 28, 1954

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RESEARCH MEMORANDUM

EXPERIMENTAL INVESTIGATION OF EFFECT OF HIGH-ASPECT-RATIO ROTOR BLADES ON PERFORMANCE OF CONSERVATIVELY-DESIGNED TURBINE

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SUMMARY

A considerable weight reduction in the turbine wheel of an aircraft gas turbine is attained through the use of high-aspect-ratio rotor blading. An experimental investigation was made to compare the performance of a turbine of conservative aerodynamic design having shrouded rotor blades with an aspect ratio of 4.48 with that obtained from both a shrouded and an unshrouded rotor design with aspect ratio of 2.24. The use of high-aspect-ratio rotor blades had a negligible effect on the turbine efficiency.

INTRODUCTION

In the design of aircraft gas turbines, a considerable weight reduction in the turbine wheel is obtained through the use of high-aspect-ratio rotor blading. For example, if, for the same blade height, the chord of a rotor blade is halved while the required number of blades is doubled in order to retain the design solidity, the cross-sectional area, and therefore the weight, of each blade is reduced by a factor of 4. In this way the over-all weight of the rotor can be reduced by about half.

In order to minimize the turbine weight, it is desirable to shorten the blade chord as much as possible. However, mechanical design and vibration problems limit the extent to which this can be done. The aerodynamic flow conditions within the turbine will also be affected by the use of high-aspect-ratio blading. As the blade chord is shortened, the streamline curvatures, and therefore pressure gradients, are correspondingly increased, and thus the boundary-layer flow conditions are affected. The secondary-flow patterns are changed when high-aspect-ratio blading is used. It will probably be necessary to shroud the rotor blades to overcome mechanical vibration of the long thin blades, which may also affect the turbine aerodynamic performance. In a turbine for which there is a large amount of axial divergence of the annulus, causing relatively

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large radial shifts in flow, the use of high-aspect-ratio blading will increase the radial accelerations required and thereby might affect turbine performance appreciably.

The purpose of this investigation at the NACA Lewis laboratory was to determine the effect on performance of using high-aspect-ratio turbine rotor blading for a turbine having conservative aerodynamic design. The turbine was designed with straight annulus walls, and therefore the effects of radial shifts in flow were relatively small. The performance of a turbine having a rotor blade with an axial chord of 1.25 inches and a height of 2.80 inches, giving an aspect ratio of 2.24 (herein referred to as the "reference turbine"), is compared with that of a turbine with rotor blades having half the chord and therefore double this aspect ratio. In designing the high-aspect-ratio rotor, the blade height was held constant while the axial chord and the blade profile coordinates were reduced by a factor of 2 at each radius. Since it was necessary to shroud the rotor in order to prevent the long thin blades from vibrating excessively, the performance of this high-aspect-ratio turbine was compared with the performance of both the unshrouded and shrouded reference turbine configurations (ref. 1).

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DESCRIPTION OF TURBINE AND EXPERIMENTAL PROCEDURE

The aerodynamic design of the turbines used in this investigation is given in detail in reference 2. The following specifications are repeated herein (symbols defined in the appendix):

Equivalent weight flow, $w\sqrt{\theta_1}/\delta_1$, lb/sec	16.60
Equivalent design work, $\Delta h'/\theta_1$, Btu/lb	16.14
Over-all stagnation pressure ratio, p_1'/p_3'	1.751
Equivalent mean blade speed, $U_m/\sqrt{\theta_1}$, ft/sec	625
Turbine hub-tip radius ratio, r_h/r_T	0.60
Turbine outer diameter, d_T, ft	1.167

The turbine was designed for assumed free-vortex flow and simple radial equilibrium at the exit of both stator and rotor blades.

The rotor blade profile design is shown in figure 1 for the reference rotor having 44 blades and an aspect ratio of 2.24. The high-aspect-ratio rotor blade profiles were obtained by dividing all the blade coordinates by a factor of 2 while holding the blade height constant, giving an aspect ratio of 4.48 with 88 blades. The reference rotor was run both with and without a shroud band. A diagrammatic comparison of the three configurations considered is shown in figure 2. The tip clearance was 0.030 inch for all three configurations. Figure 3 is a photograph of the high-aspect-ratio rotor.

The high-aspect-ratio blades were cast by a lost-wax process of manganese-bronze material. The measured throat width for these blades was equal to one-half the measured throat width of the reference rotor blade within 1 percent.

The experimental procedure given in detail in reference 2 was followed in determining the performance of each of the three turbine configurations. Over-all performance data were taken at nominal values of stagnation pressure ratio p_1'/p_3' from 1.30 to the maximum obtainable, while the wheel speed was varied from 0.60 to 1.00 of equivalent design speed in 0.05 intervals. Several of the high-aspect-ratio rotor blades failed when operation at blade speeds above the design value was attempted.

The brake internal efficiency, which is based on expansion between the entrance and exit stagnation pressures, was used to express turbine performance. It is defined as $\eta_t = E/(h_1' - h_3')_{is}$, where E is the measured turbine shaft work. The ideal enthalpy drop $(h_1' - h_3')_{is}$ was computed from the values of entrance and exit stagnation pressure and entrance stagnation temperature. The exit stagnation pressure was computed by adding to the measured static pressure a dynamic pressure corresponding to the axial component of the exit velocity computed from continuity considerations. An average measured exit temperature was used in these calculations.

RESULTS AND DISCUSSION

The results obtained from the performance studies of the three rotor blade configurations are presented in figures 4 to 6. The performance maps for the unshrouded and shrouded reference rotor blade configurations are given in figures 4(a) and (b), respectively. A discussion of the comparative performance of these two configurations is given in reference 1. The performance map for the high-aspect-ratio rotor blade configuration is given in figure 4(c).

A direct comparison of the performance of the three rotor blade configurations can be better obtained from figures 5 and 6. The more significant comparison is between the unshrouded reference and the shrouded high-aspect-ratio rotor blade configurations. For, while the shroud was found to be disadvantageous for the reference turbine rotor blade design investigated (ref. 1), it becomes a practical necessity for damping vibrations in the long, thin, high-aspect-ratio rotor blades. The turbine designer would, therefore, make a choice between an unshrouded rotor of relatively low aspect ratio and a shrouded high-aspect-ratio rotor. The maximum efficiency obtained at each pressure ratio is plotted against the pressure ratio in figure 5. The unshrouded reference and the high-aspect-ratio rotor blades have very nearly the same maximum efficiency over the whole range of pressure ratios investigated. The efficiency measured at design blade speed is presented in figure 6. Again it is evident that the use of high-aspect-ratio rotor blades had a negligible effect on the turbine efficiency.

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SUMMARY OF RESULTS

In an experimental investigation comparing the performance of a turbine of conservative aerodynamic design having shrouded rotor blades with an aspect ratio of 4.48 with that obtained from both a shrouded and an unshrouded rotor blade design with aspect ratio of 2.24, it was found that the use of high-aspect-ratio rotor blades had a negligible effect on the turbine efficiency.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, March 18, 1954

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APPENDIX - SYMBOLS

The following symbols are used in this report:

d diameter, ft

E turbine shaft work, Btu/lb

h specific enthalpy, Btu/lb

p absolute pressure, lb/sq ft

r radius, ft

T temperature, $^{\circ}R$

U blade velocity, ft/sec

w weight-flow rate of gas, lb/sec

η_t brake internal efficiency

δ pressure-reduction ratio, p/p_0

θ temperature-reduction ratio, T/T_0

Subscripts:

des design

h hub

is isentropic

m mean radius

T tip

0 NACA sea-level air

1 measuring station in surge tank (inlet stagnation condition)

2 measuring station downstream of stator

3 measuring station downstream of rotor

Superscript:

' stagnation state

REFERENCES

1. Hauser, Cavour H., and Plohr, Henry W.: Experimental Investigation of the Effect of a Shrouded Rotor on the Performance of a Conservatively Designed Turbine. NACA RM E54C11, 1954.

2. Heller, Jack A., Whitney, Rose L., and Cavicchi, Richard H.: Experimental Investigation of a Conservatively Designed Turbine at Four Rotor-Blade Solidities. NACA RM E52C17, 1952.

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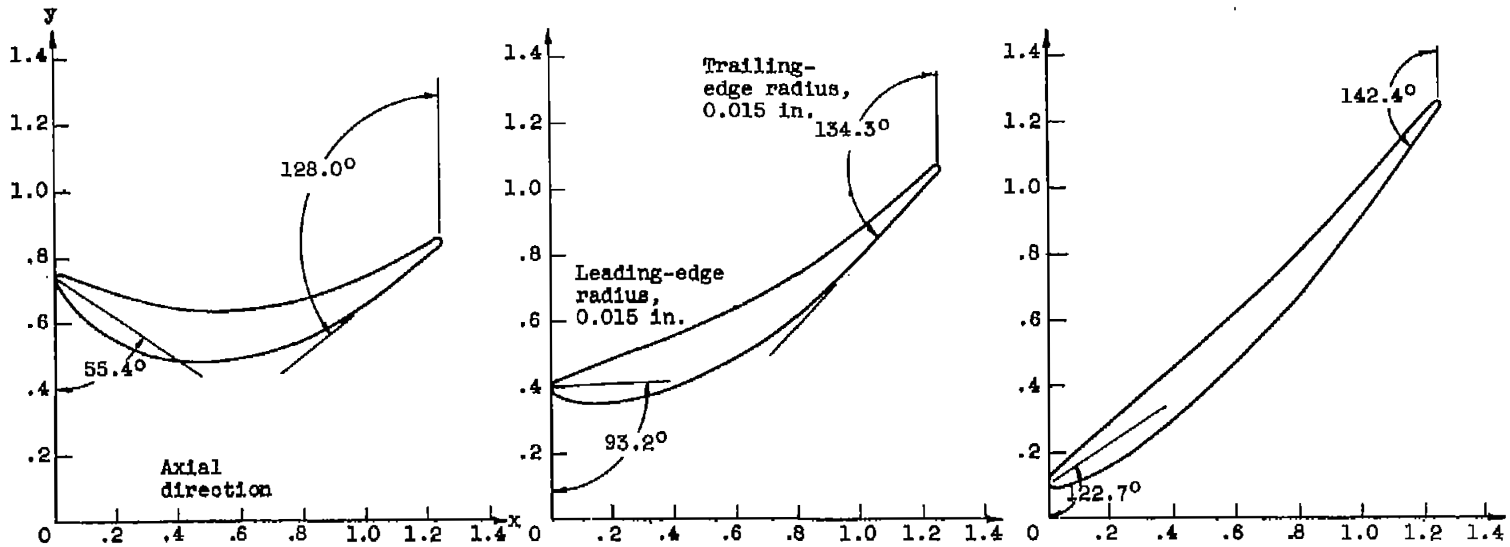

Hub section (radius, 0.350 ft)

x, in.	y	
	Suction, in.	Pressure, in.
0	0.735	0.736
.1	.616	.725
.2	.549	.687
.3	.512	.661
.5	.489	.637
.7	.516	.654
.9	.594	.701
1.10	.728	.789
1.25	.851	.851

Mean section (radius, 0.467 ft)

x, in.	y	
	Suction, in.	Pressure, in.
0	0.397	0.397
.1	.362	.451
.2	.359	.486
.3	.372	.521
.5	.448	.598
.7	.546	.690
.9	.702	.808
1.1	.902	.961
1.25	1.063	1.063

Tip section (radius, 0.524 ft)

x, in.	y	
	Suction, in.	Pressure, in.
0	0.105	0.105
.1	.114	.215
.2	.184	.298
.3	.230	.377
.5	.388	.541
.7	.574	.713
.9	.801	.900
1.1	1.056	1.110
1.25	1.253	1.253

Figure 1. - Blade-section profiles and coordinates for turbine rotor blade.

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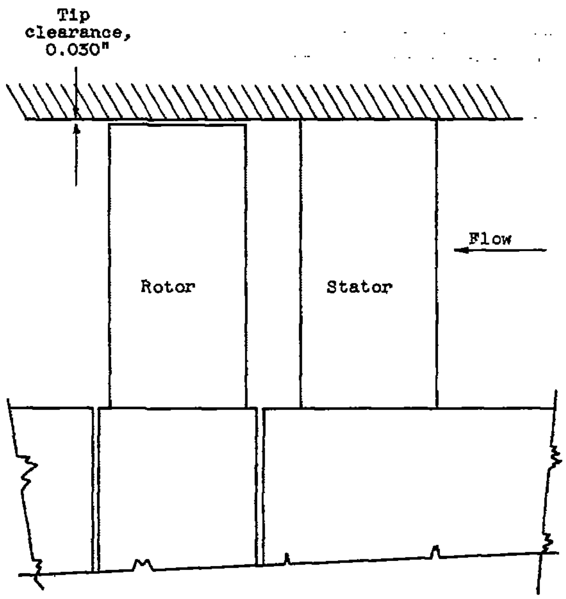
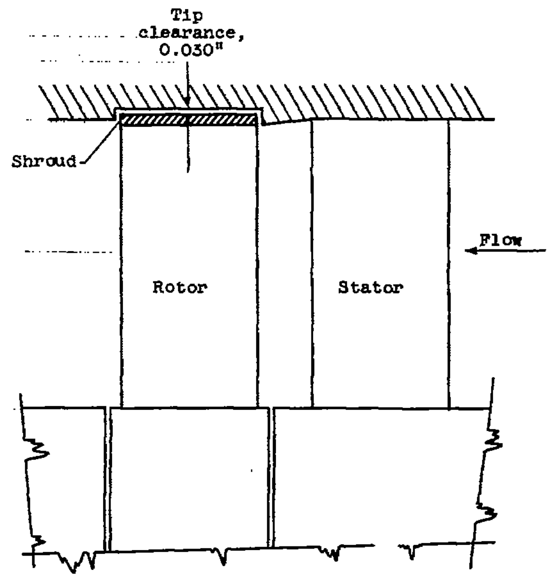
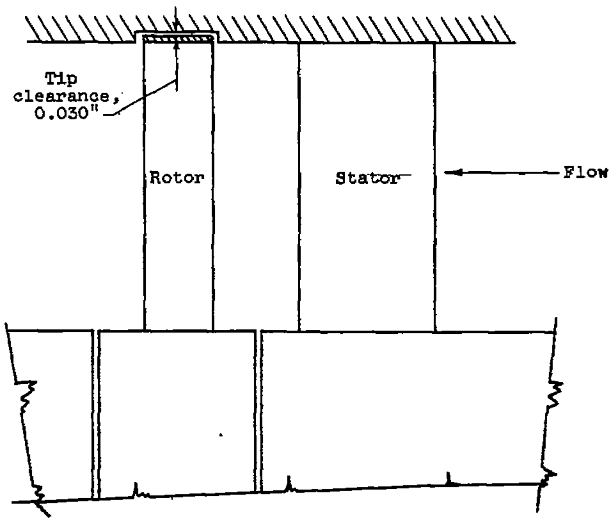


(a) Unshrouded reference rotor. Aspect ratio, 2.24.



(b) Shrouded reference rotor. Aspect ratio, 2.24.



(c) High-aspect-ratio shrouded rotor. Aspect ratio, 4.48.

Figure 2. - Diagrams of shrouded, unshrouded, and high-aspect-ratio rotor blade configurations.

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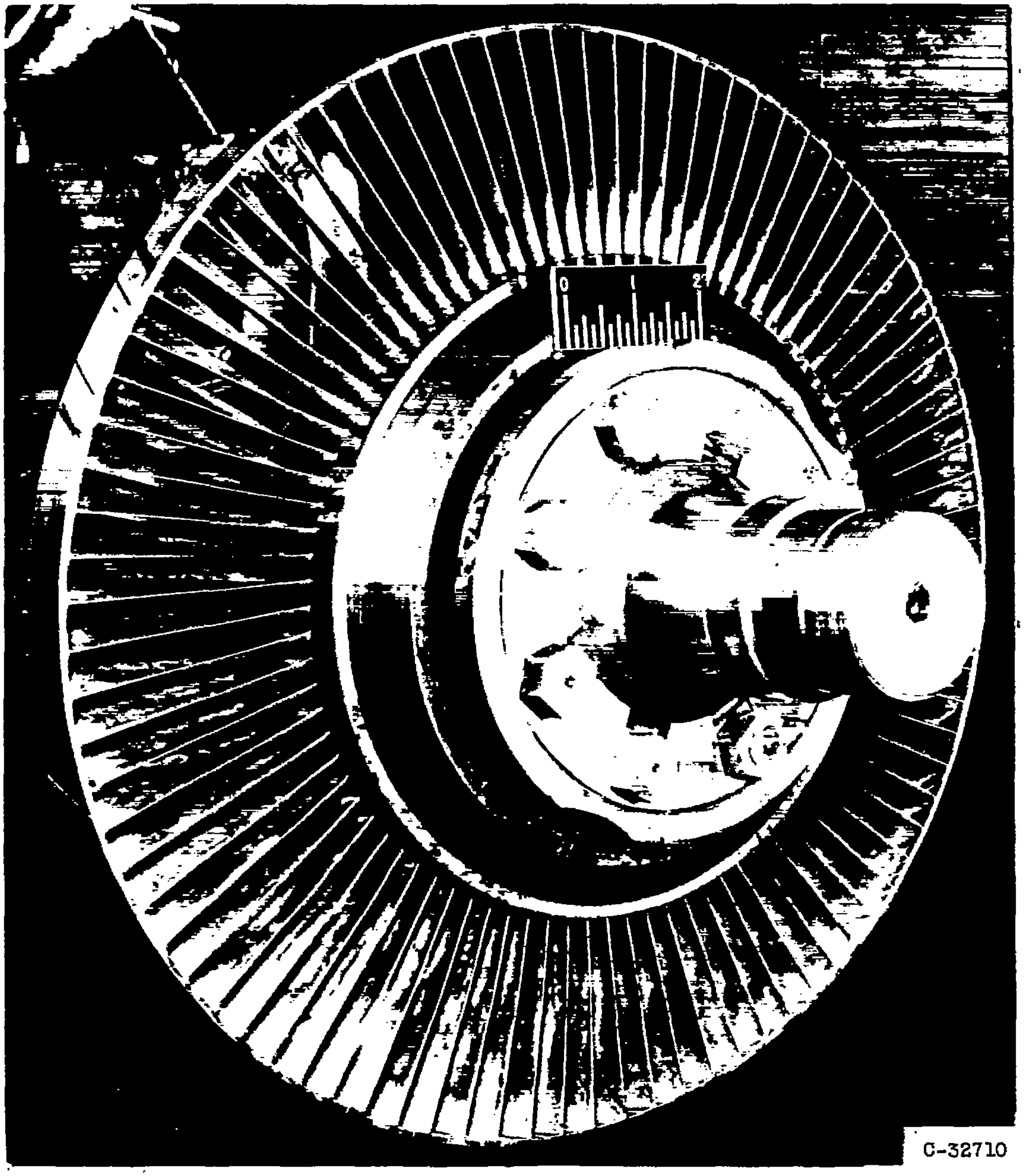
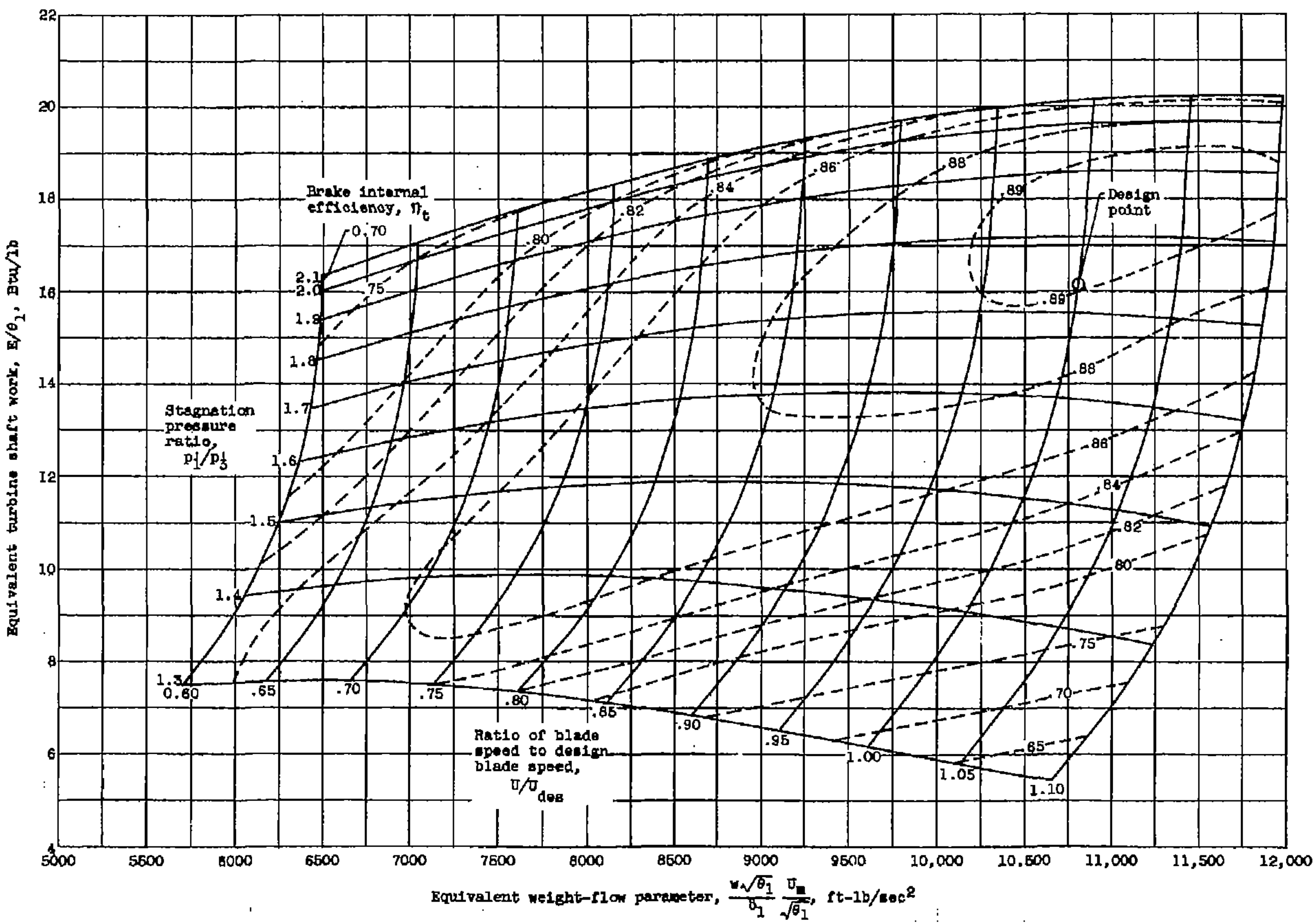
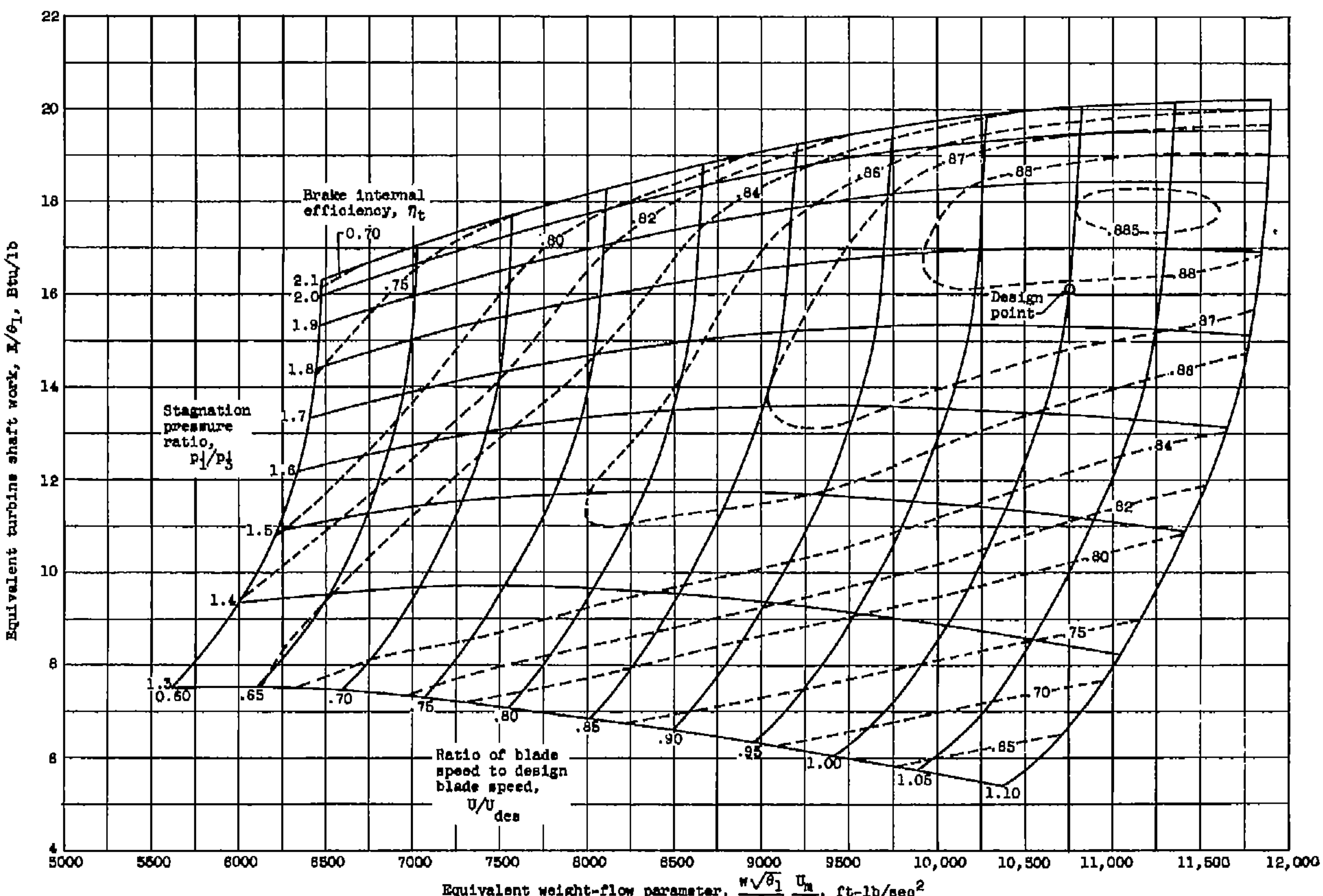


Figure 3. - Photograph of high-aspect-ratio turbine rotor.



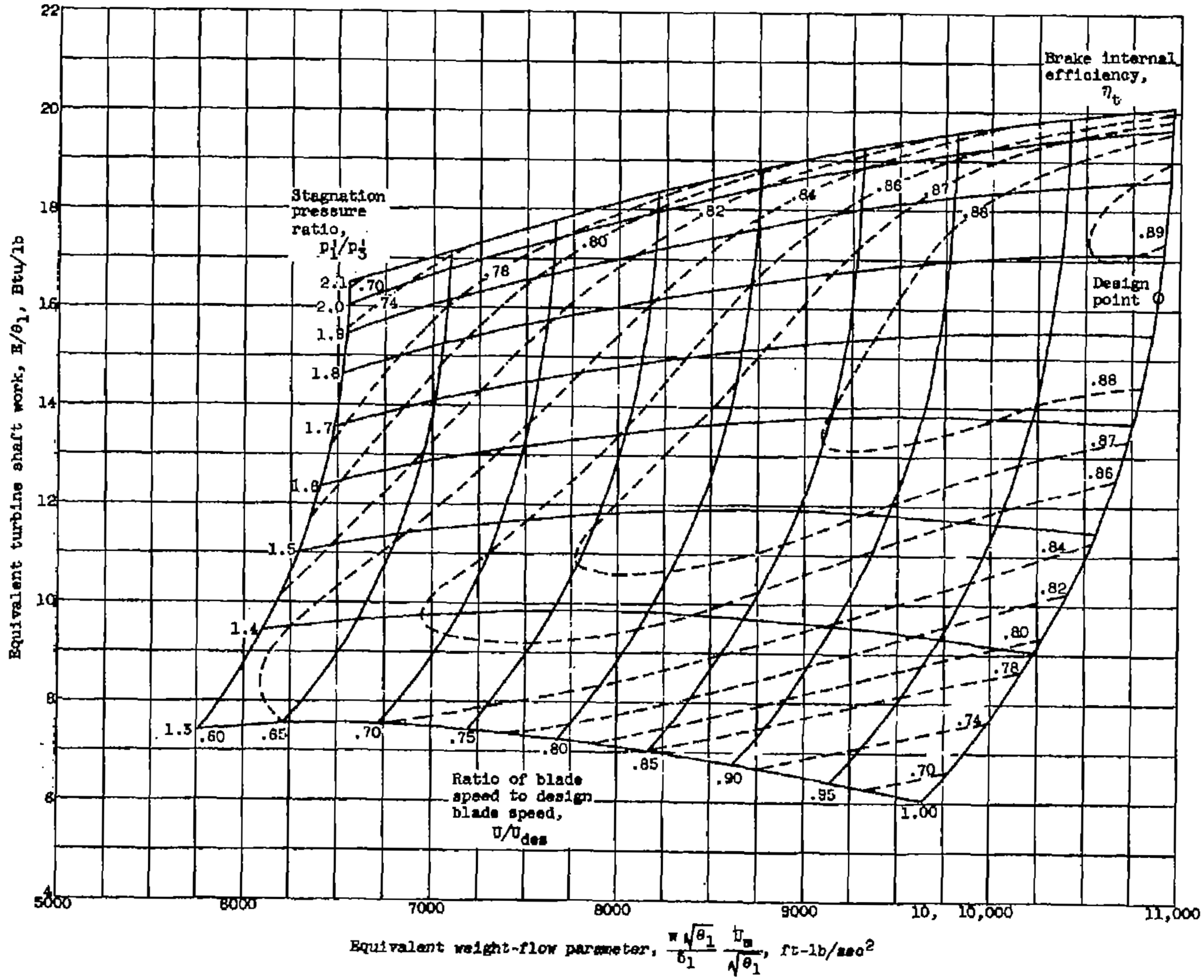
(a) Unshrouded reference rotor. Aspect ratio, 2.24.

Figure 4. - Over-all turbine performance.



(b) Shrouded reference rotor. Aspect ratio, 2.24.

Figure 4. - Continued. Over-all turbine performance.



(c) High-aspect-ratio shrouded rotor. Aspect ratio, 4.48.

Figure 4. - Concluded. Over-all turbine performance.

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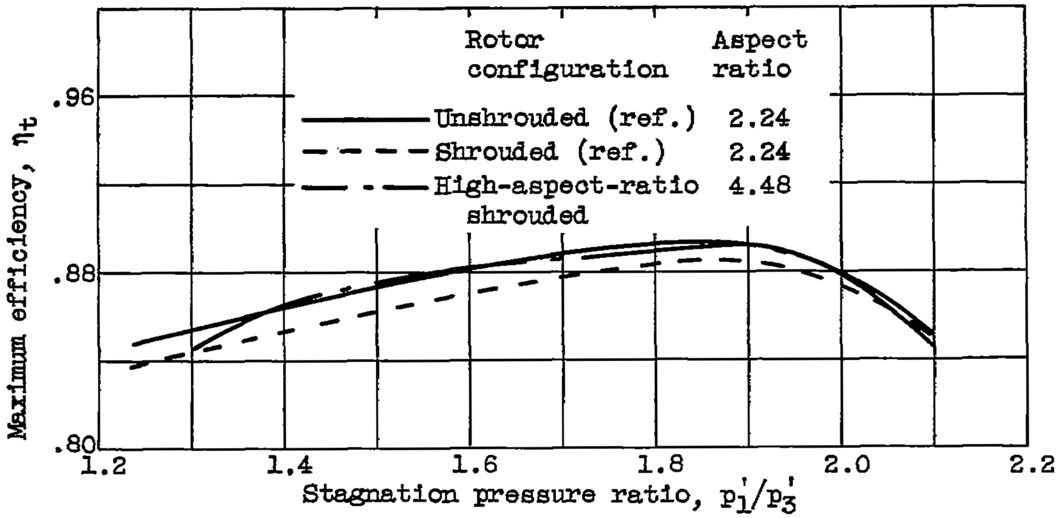

Figure 5. - Effect of high-aspect-ratio rotor blades on maximum turbine efficiency.

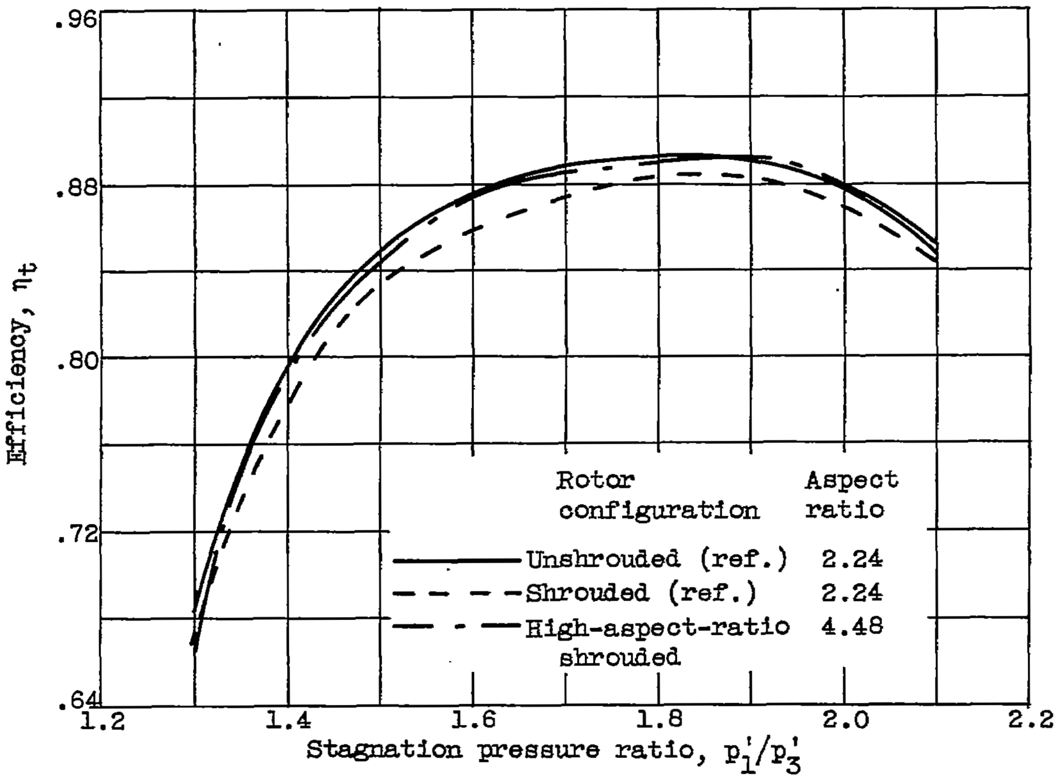

Figure 6. - Effect of high-aspect-ratio rotor blading on turbine efficiency for design blade speed. ($U/U_{des} = 1.0$)

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